Mixing by Tidal Interaction with Sloping Boundaries

Sonya Legg
Woods Hole Oceanographic Institution
MS 21
Woods Hole, MA 02543
phone: (508) 289-2801 fax: (508) 457-2181 email: slegg@whoi.edu

Carl Wunsch
Department of Earth, Atmospheric and Planetary Sciences
Room 54-1524
Massachusetts Institute of Technology
77 Massachusetts Ave.
Cambridge, MA 02139
phone: (617) 253-5937 fax: (617) 253-4464 email: cwunsch@ocean.mit.edu

Award #: N00149810096
http://charybdis.whoi.edu/sonya/LIWI

LONG-TERM GOAL

The long-term goals of this project are to obtain an understanding of the mechanisms by which tidal energy is used to vertically mix the ocean against the action of gravity. Ultimately better parameterizations of the mixing caused by tides will result, allowing better prediction of coastal dynamics, biogeochemistry and sediment transport and the oceanic general circulation.

OBJECTIVES

The process of mixing by tides interacting with topography involves several stages. First some fraction of the energy contained in the barotropic tide must be converted into baroclinic energy, through the generation of internal tides and turbulent boundary layers. Secondly, the energy in the internal tides must be transmitted into smaller vertical wavelengths, thereby increasing the vertical shear of the motion. When vertical shears are sufficiently strong, instability may result, leading to overturning and mixing. Finally, the mixed fluid is transported away from the mixing region modifying the ocean stratification. The net effect of the tides on the ocean stratification depends on the efficiency of all three processes.

Our objectives are to understand (a) the generation of internal tides by the interaction between barotropic tides and topography including finite-amplitude 3-dimensional variations in topography, finite-amplitude barotropic tidal forcing, non-hydrostatic effects and the boundary layer processes; (b) the mixing generated by internal tides reflecting from a sloping boundary in the presence of both 2 and 3-dimensional variations in slope, and finite rotation; and (c) the mechanisms of lateral and isopycnal transport of mixed fluid away from the boundary induced by the secondary circulations generated through spatial variations in mixing. Earlier studies have ignored 3-dimensional large amplitude variations in topography and non-hydrostatic effects (which are important for small-aspect ratio motion).

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **1998**	2. REPORT TYPE	3. DATES COVERED **00-00-1998 to 00-00-1998**
4. TITLE AND SUBTITLE **Mixing by Tidal Interaction with Sloping Boundaries**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Woods Hole Oceanographic Institution,Woods Hole,MA,02543**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM002252.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**4**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

APPROACH

We use high-resolution numerical simulations to explicitly resolve the turbulent mixing processes. For such simulations we require a numerical model which can (a) capture the non-hydrostatic physics of overturning and mixing processes (b) include arbitrary 3-dimensional variations in topography. The Marshall et al (1997a,b) code (known as the MIT ocean model), which is non-hydrostatic, and includes topography through a finite-volume formulation, is such a model. We will carry out 3 different groups of simulations: (a) We will impose topography, barotropic tides and subinertial flows suggested by recent observations (e.g. Norfolk canyon region: Polzin et al (1998) (private communication), and Monterey Canyon region, Rosenfeld et al, 1998) (private communication), and investigate the internal tide generated by the flow-topography interactions, comparing these results with earlier models which assume small-amplitude (e.g. Bell, 1975) or 2-dimensional finite amplitude (Baines 1982) topography. (b) We will impose internal tide forcing and investigate the interaction with a 2-dimensionally varying slope, focusing on the influence of finite rotation on the overturning and mixing, and the effect of slope variations in localizing mixing, comparing with earlier laboratory and numerical studies with uniform slope and no rotation (Ivey and Nokes, 1989; Slinn and Riley, 1998). (c) We will impose internal tide forcing and investigate the interaction with 3-dimensional topography variations, focusing on the localization of mixing, and the resultant secondary circulation and lateral transports of mixed fluid.

WORK COMPLETED

The project is just getting underway. In the short time available, we have configured the MIT model for small domains with topography, adding open-boundary conditions at the sidewalls. We have carried out numerous tests of the code, finding good agreement with analytic solutions. A series of simulations of internal tide generation by barotropic tidal forcing, for topography characterized by a slope with regular ridges and troughs aligned across the slope (“corrugated slope") has been explored.

Calculations of internal wave interaction with a uniform slope provided a test of the model by comparing the internal wave reflection with theoretical predictions.

Connections have been made with other investigators involved in LIWI, and in particular, obtained the currents and stratification from the Norfolk Canyon observed by K. Polzin and others at WHOI for use in forcing the model.

RESULTS

Our calculations of the internal tides generated by barotropic along-slope tides on a corrugated sloping boundary (an idealization of the Norfolk Canyon region) give solutions for small amplitude corrugations, and small amplitude currents, which agree well with linear predictions (e.g. Bell 1975). We will shortly investigate the influence of increasing amplitude in topography and currents, to identify the influence of non-linearity and non-hydrostatic effects.

Calculations of internal wave reflection from uniformly sloping boundaries agree with predictions (Phillips, 1977; Eriksen, 1982). In particular, the finite volume topography formulation of the model accurately captures the reflection of the internal tide from subcritical slope, without introducing any spurious supercriticality, unlike conventional z-coordinate models. At slopes close to the critical angle, the energy of the reflected wave is concentrated along the slope. Rotation introduces along-slope currents of magnitudes only slightly smaller than the across slope velocities. These calculations have

been carried out for very small amplitude internal tides, to focus on the linear effects. We will shortly increase the wave amplitude, to examine the mixing and overturning.

IMPACT/APPLICATION

Our results should help the interpretations of observations of tidally forced flows on the continental slope observed by LIWI investigators and others. We anticipate our results will eventually allow better parameterizations of tidal mixing to be developed, allowing better prediction of coastal dynamics, biogeochemical processes and the oceanic general circulation (Munk and Wunsch, 1998).

TRANSITIONS

We are communicating our results to other members of LIWI, K. Polzin, L. Rosenfeld, and others, to help interpret their observations.

RELATED PROJECTS

This project examines processes closely related to observations included in LIWI (Polzin, Toole and Schmitt and Paduan, Rosenfeld, Kunze and Gregg). The work is related to the NSF-supported general circulation studies of Wunsch.

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